6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.4 FIRE PROTECTION PIPING

6.4.4.1 SUSPENDED FIRE PROTECTION PIPING

This category covers fire protection sprinkler systems and piping. These systems and piping are subject to the requirements in NFPA 13, *Standard Installation of Sprinkler Systems* (NFPA, 2007a). In some seismic zones (Design Categories C, D, E, and F), additional requirements in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and other Structures* (ASCE, 2010), may apply.

TYPICAL CAUSES OF DAMAGE

- Fire protection piping systems are sensitive to both acceleration and deformation. Vulnerable locations include joints, bends, connections to rigidly mounted equipment and risers subjected to significant relative movement between floors.
- Sprinkler heads are often damaged due to conflict with ceiling systems; this conflict may also result in impact damage to the ceiling or subsequent water damage.
- Fluids may leak from damaged joints or broken pipe; property losses and business outages are often attributed to fluid leaks from fire suppression piping. Facilities may need to be evacuated if the fire suppression system is compromised.
- Damage to any part of the fire protection system may compromise its functionality; in addition to the piping, the pumps, holding tanks, control panels, control sensors, smoke detection equipment, fire doors, etc. must all be operational. If a fire breaks out following an earthquake and the fire suppression system is not functional, significant property losses may result.

Damage Examples

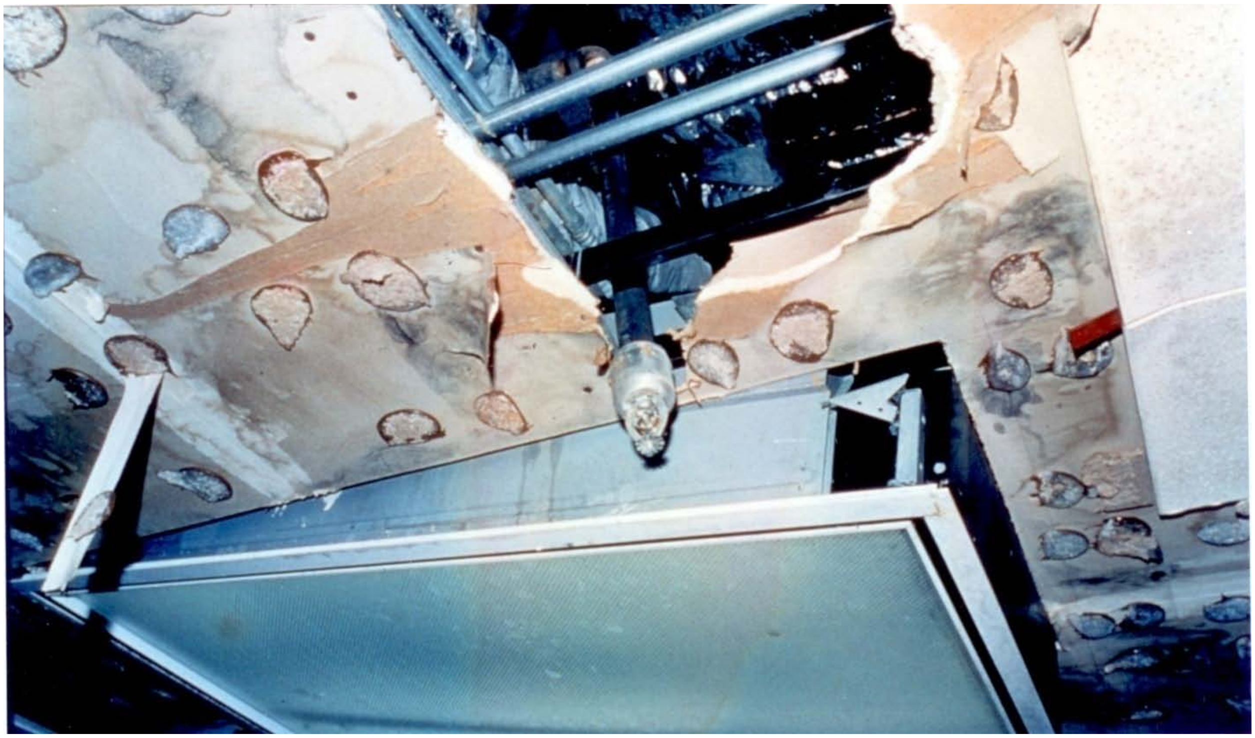


Figure 6.4.4.1-1 Sprinkler pipe ruptured at the elbow joint due to differential motion within the ceiling plenum. Water leakage from broken fire sprinklers and water lines contributed to the decision to close this hospital for several days following the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Robert Reitherman).

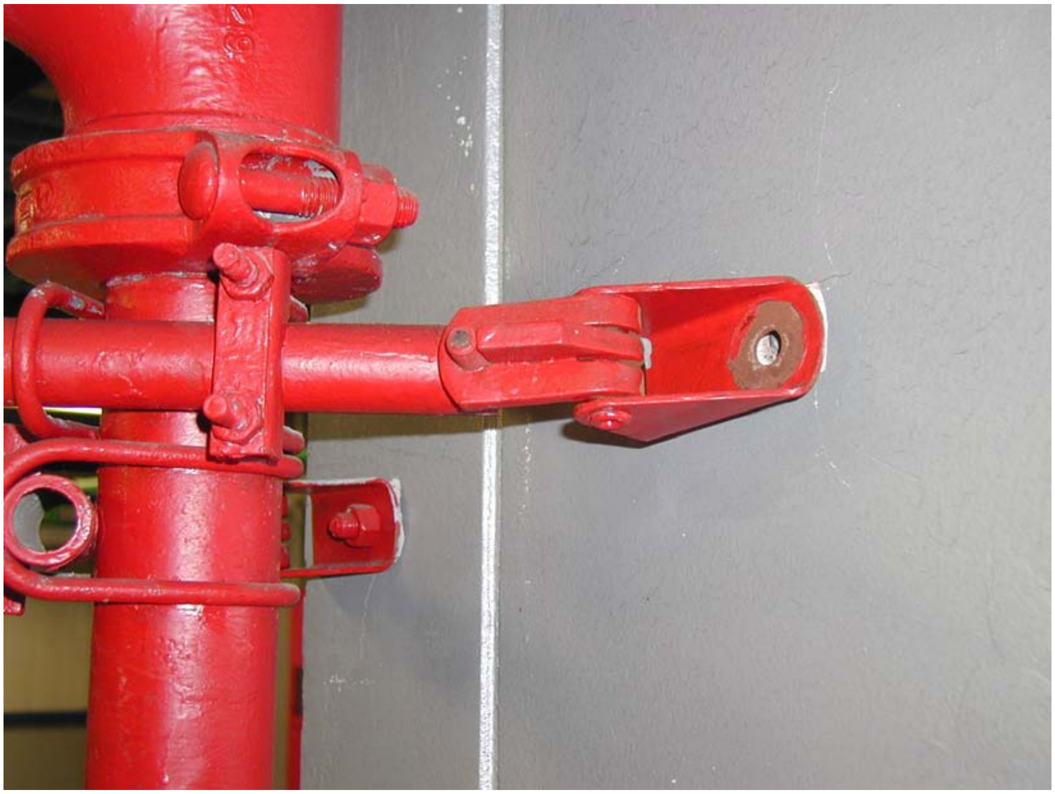


Figure 6.4.4.1-2 Wall-mounted pipe restraint failed due to inadequate connection to structural framing in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

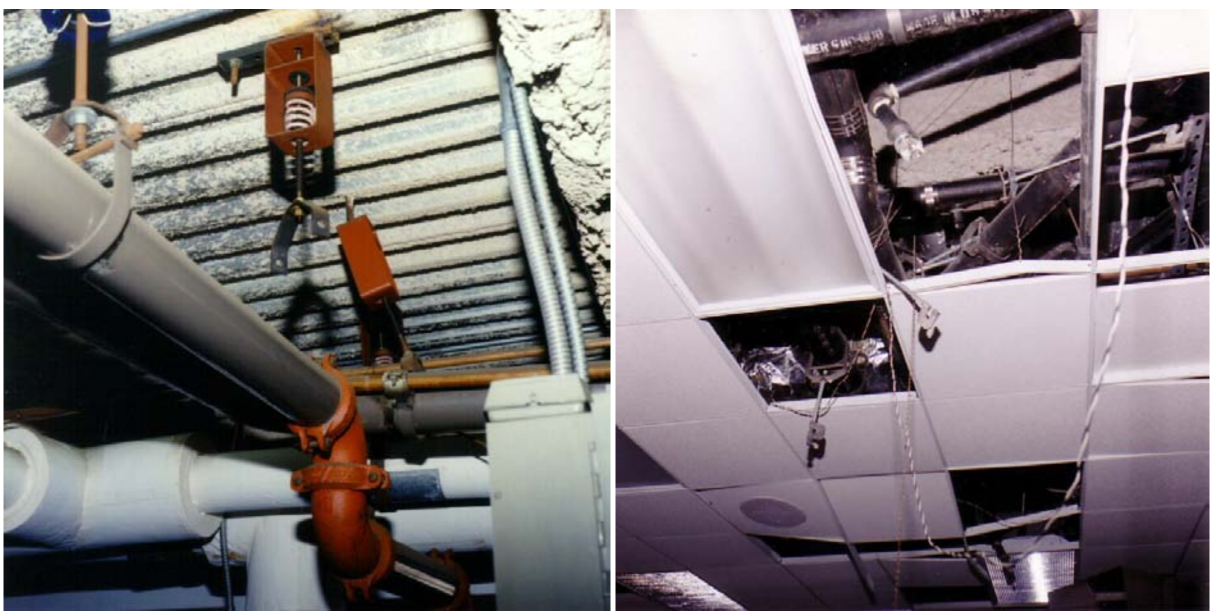


Figure 6.4.4.1-3 Damage to suspended fire protection piping from the 1994 Northridge Earthquake. Failed vibration isolators at left; failed C-clamps without beam clamp restraining straps shown at right (Photos courtesy of Mason Industries).

Figure 6.4.4.1-4 Collapse of water tank at left and broken piping disabled the fire protection system at this power plant in Port-au-Prince and led to the temporary plant closure in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.4.1-5 Unanchored holding tank slid on concrete pad, breaking fire protection piping and disabling the fire protection system in the 2010 Haiti Earthquake. In this case, the piping was well anchored but the tank was unrestrained (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.4.1-6 Damage to industrial fire protection piping located on jetty in 2001 Peru Earthquake. Longitudinal slip at U-bolt shown at left; this U-bolt still intact but other U-bolts broke and fell off the jetty. Failure of joint coupling and crushing of pipe shown at right (Photo courtesy Eduardo Fierro, BFP Engineers).

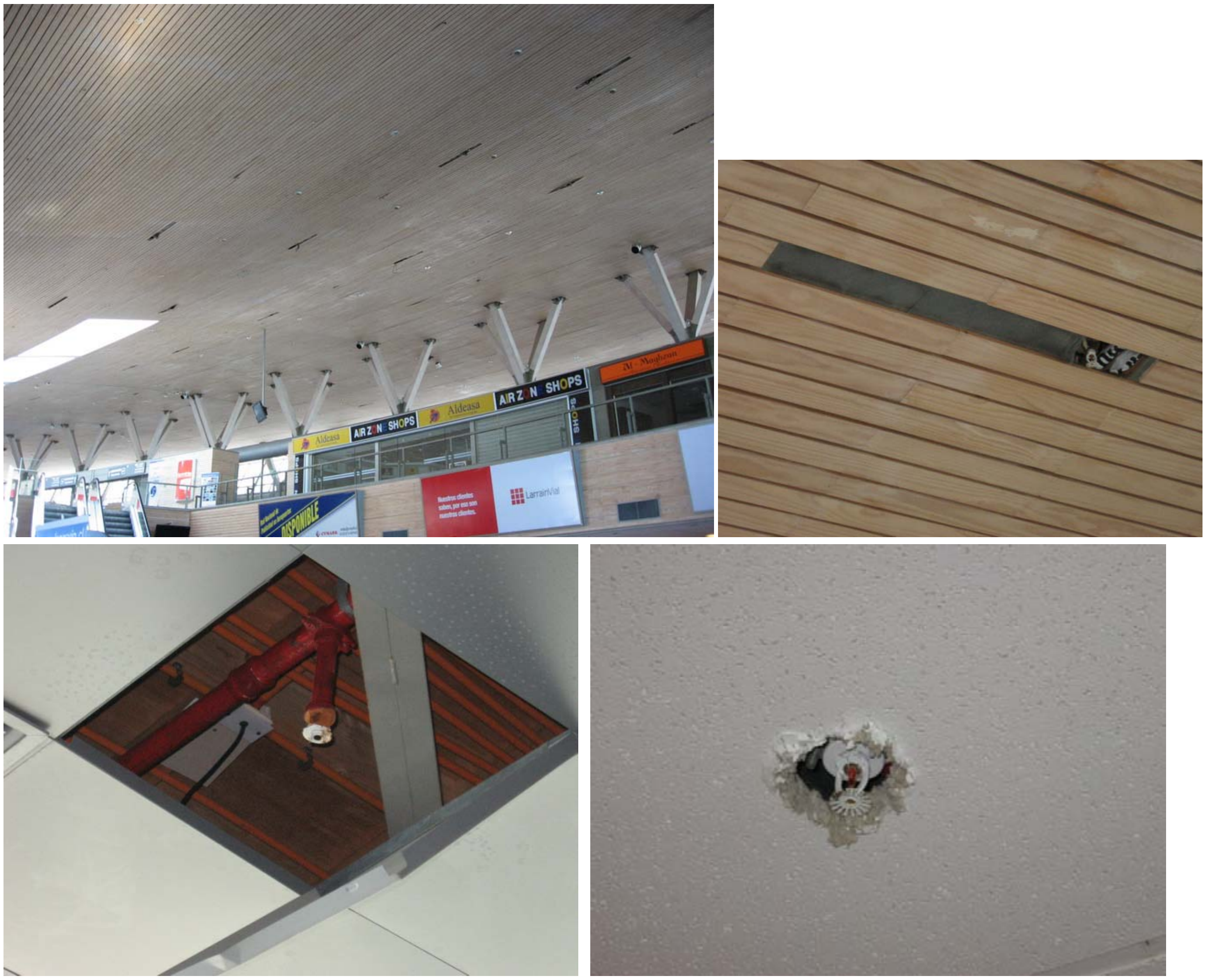


Figure 6.4.4.1-7 Conflicts between the sprinkler heads and several types of ceiling finishes resulted in damage to the ceilings, sprinkler heads and subsequent water damage at the Concepción airport in the 2010 magnitude-8.8 Chile Earthquake (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

SEISMIC MITIGATION CONSIDERATIONS

- ASCE 7-10, *Minimum Design Loads for Buildings* (ASCE, 2010), Section 13.1.3.1 specifies that systems required for life-safety purposes after an earthquake, such as fire protection systems, be classified as designated seismic systems and designed using a component importance factor, I_p, of 1.5. Designated seismic systems may require engineering calculations, equipment certification, special inspection, etc. Check the jurisdiction and applicable code for other requirements.
- NFPA 13, Standard for Installation of Sprinkler Systems (NFPA, 2007a), provides specific requirements for fire suppression systems and piping. Refer to 2006 IBC, *International Building Code* (ICC, 2006), and ASCE/SEI 7-10 Section 13.6.8 for other seismic design requirements. NFPA 13 contains prescriptive requirements for the layout of fire protection piping, with minimum spacing for vertical, lateral, and longitudinal seismic restraints. While NFPA 13 includes some exemptions for small diameter piping or hangers less than 6" long, these exemptions are not recognized explicitly in the 2006 IBC and may not provide adequate protection in areas of high seismicity. Check with the jurisdiction for applicable requirements and exemptions.
- Fire suppression systems include many components, all of which must be properly restrained or anchored for the system to function as intended. Pumps, holding tanks, control panels, control sensors, piping and sprinkler heads must all be protected from earthquake damage. In addition to seismic restraints for each component, it is important to check for potential conflicts with other structural and nonstructural elements and for falling hazards.
- Seismic restraint details for pressure piping shown in Sections 6.4.3.1 through 6.4.3.8 can be adapted for use with fire protection piping. One significant difference is that components, supports, and seismic restraint hardware for fire protection systems must all be certified (UL listed, FM approved, etc.). This requirement also applies to seismic restraint components for fire protection control panels, pumps, and holding tanks.
- Some proprietary systems are available that reduce the vulnerability of sprinkler heads in suspended ceiling grids. One such system provides flexible sprinkler drops so the sprinkler head can move freely with the ceiling grid (see Figure 6.4.4.1-11); this proprietary system has been shake table tested. Another system is an "integrated" ceiling system where the ceiling grid, acoustical panels, lighting, ducts and air diffusers, and sprinkler piping are all shop assembled in modules; this system alleviates the problem of differential movement of the component parts. These types of solutions may greatly reduce the seismic vulnerability of sprinkler heads. Check the internet for these and other proprietary systems.

- Two details are included here that are unique to fire protection systems. Figure 6.4.4.1-11 provides one type of detail for a sprinkler drop and Figure 6.4.4.1-12 provides a detail for an end of line restraint required for feeds or cross mains.
- Several engineered seismic bracing systems are commercially available and can be customized for most applications. Check the internet for these proprietary systems and whether they are UL listed, OSHPD approved, FM approved, etc. as required.
- For California schools and essential facilities, DSA Policy 10-01, *Plan Submittal Requirements: Automatic Fire Sprinkler Systems (AFSS)* (California Department of General Services, 2010b), states that as of July 2010, deferred submittals for fire protection systems will no longer be accepted. These systems must be submitted as a complete package as part of the initial project submittal.

Mitigation Examples

Figure 6.4.4.1-8 There was no damage to the *fire suppression equipment in this control room in the 2001 Peru E*arthquake because the pump and the control panel were well anchored and the piping had flexible connections with adequate sized wall penetration and no overhead falling hazards (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.4.1-9 Transverse and longitudinal restraints on fire protection distribution line (Photo courtesy of Cynthia Perry, BFP Engineers).

Figure 6.4.4.1-10 Flexible hose between sprinkler line and ceiling allowing the sprinkler head to move with the suspended ceiling without causing damage to the sprinkler system (Photo courtesy of Flexhead).

Mitigation Details

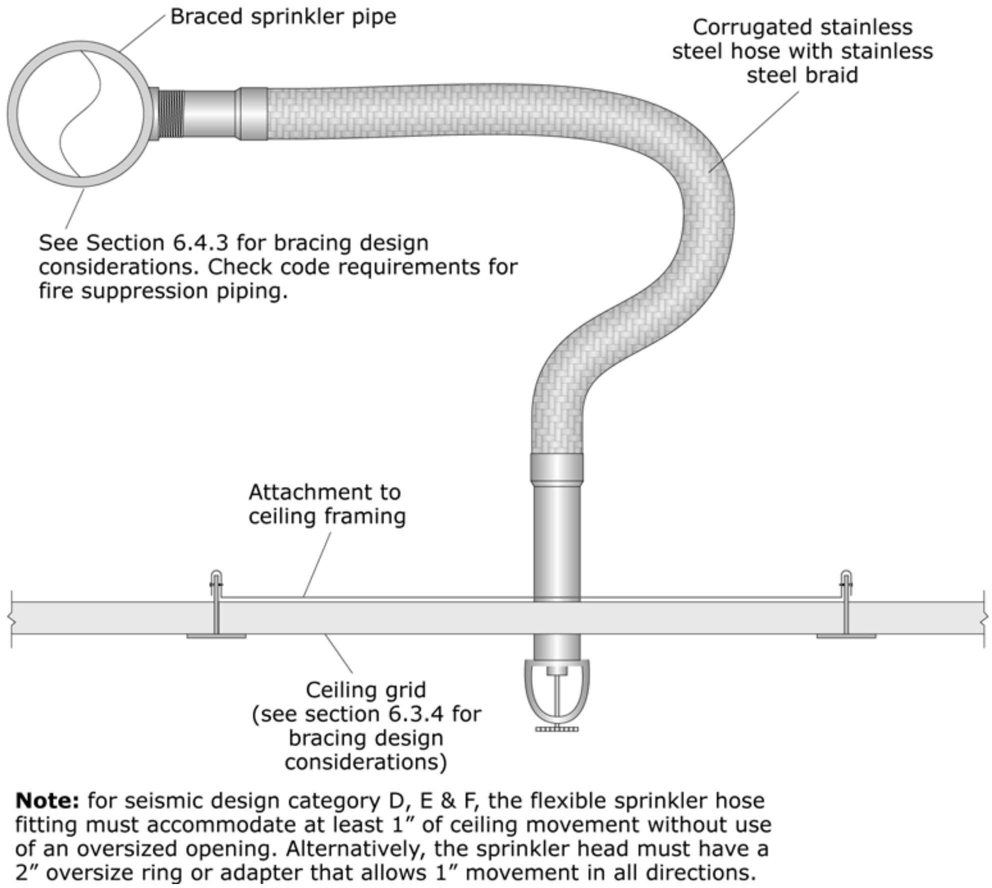


Figure 6.4.4.1-11 Flexible sprinkler drop (ER).

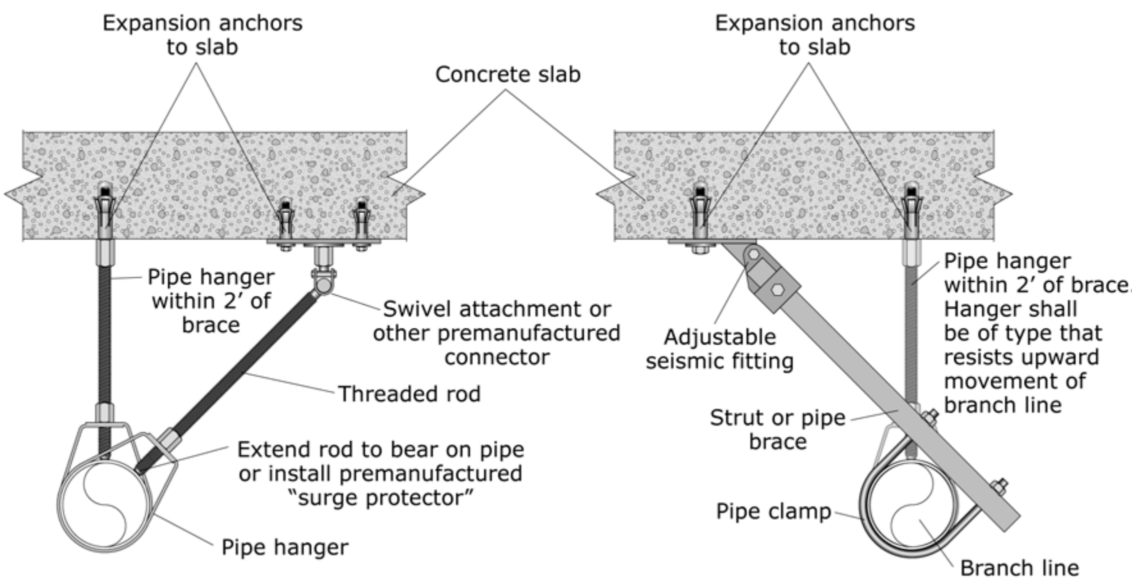


Figure 6.4.4.1-12 End of line restraint (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.5 FLUID PIPING, NOT FIRE PROTECTION

6.4.5.1 HAZARDOUS MATERIALS PIPING

This category covers fluid piping, other than pressure piping or fire protection piping, that transfers fluids under pressure, by gravity, or that are open to the atmosphere. Specifically, the fluids in this category are hazardous and flammable liquids that would pose an immediate life safety danger due to their inherent properties. Hazardous materials and flammable liquids that would pose an immediate life safety danger if exposed are described in NFPA Standards such as NFPA 49, *Hazardous Chemicals Data*, and NFPA 491, *Hazardous Chemical Reactions,* as listed in the NFPA Fire Protection Guide to Hazardous Materials (NFPA, 2010).

TYPICAL CAUSES OF DAMAGE

- Hazardous fluid piping is sensitive to both acceleration and deformation. Vulnerable locations include joints, bends, connections to rigidly mounted equipment and risers subjected to significant relative movement between floors. These piping systems have failure modes common to all piping systems, but the consequences of failure are more severe.
- Fluids may leak from damaged joints or broken pipe. Hazardous and flammable fluid spills may result in fire, explosion, or evacuation to avoid personal exposure. The risk for injury, property losses and business outages is high.
- Damage to any part of the hazardous piping system may compromise its functionality and connected equipment or systems may be disabled due to piping leaks or failures. For example, many hazardous piping systems are designed with safety systems to reduce the likelihood of leakage such as secondary containment with double walled pipes, automatic shut-off or excess flow valves, leak detection systems, use of non-jointed piping and highly ductile pipe materials, etc. If not properly designed, installed and maintained, any of these secondary or backup systems could also be damaged resulting in hazardous material leaks or loss of functionality.

Damage Examples

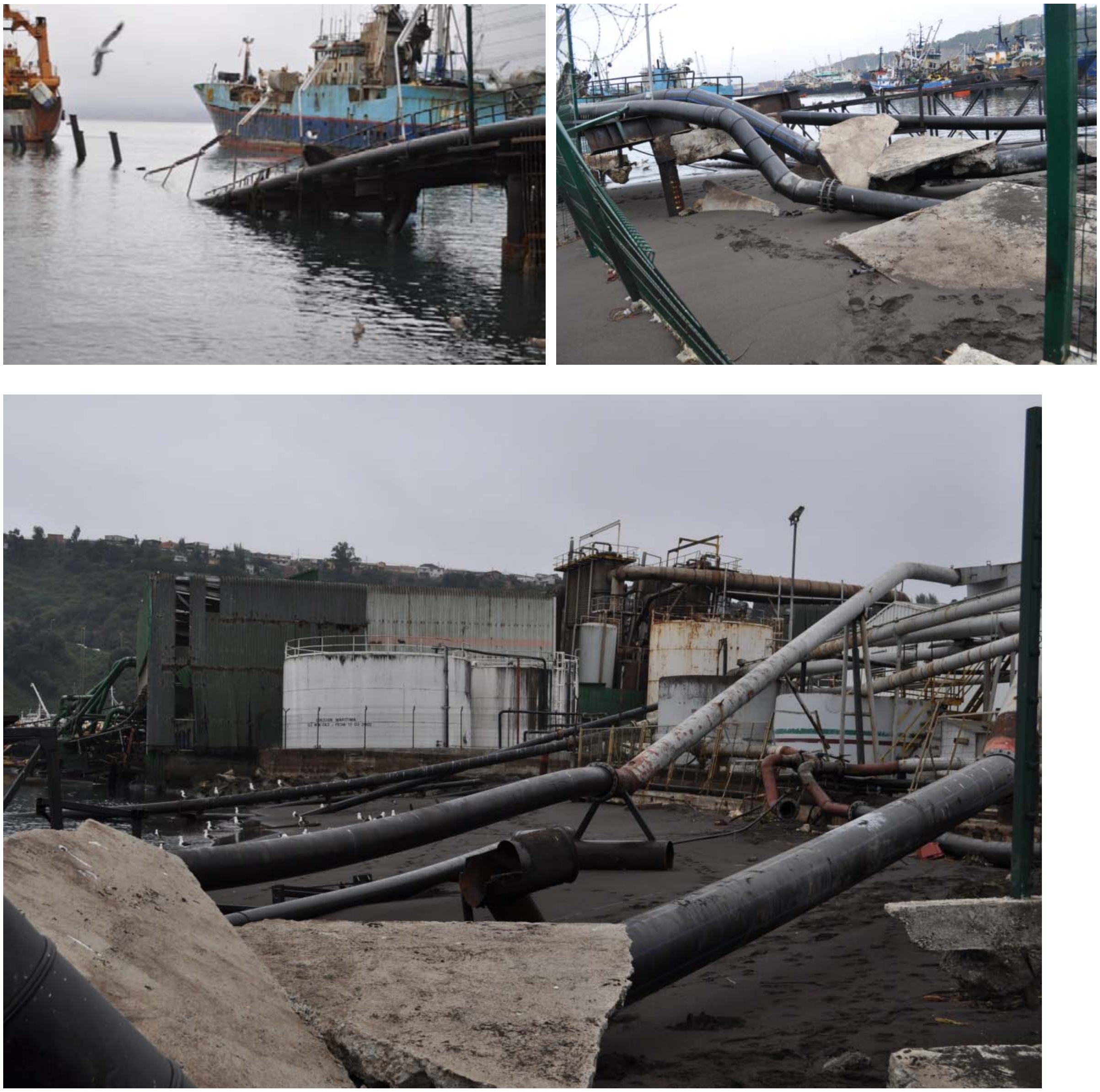


Figure 6.4.5.1-1 Earthquake, liquefaction, and tsunami damage to oil supply lines at the port in Talcahuano in the 2010 magnitude-8.8 Chile Earthquake. The pier in upper photo collapsed over much of its length dragging the pipes down into the water; this caused tension failures in some pipe joints and also resulted in structural damage to the buildings (Photos courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.5.1-2 Basement level at power plant in Port-au-Prince flooded with oil and water in the 2010 magnitude-7 Haiti Earthquake creating hazardous conditions for inspection and clean-up (Photos courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.5.1-3 Elephant foot damage to inadequately anchored fuel tank in the 2010 Chile Earthquake also resulted in damage to fuel lines. Close-up photo shows failed pipe at welded joint (left) and pipe segment with attached valve (foreground) tore out of the tank wall (Photos courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Fuel and natural gas lines are found in many common settings, but this category also covers more hazardous types of piping found in industrial facilities, power plants or hospitals. The national standard for pressure piping, ASME B31.3, *Process Piping* (ASME, 2008), defines hazardous fluid service as "a fluid service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to person on breathing or bodily contact, even when prompt restorative measures are taken."
- ASCE 7-10, *Minimum Design Loads for Buildings and other Structures* (ASCE, 2010), requires the use of a component importance factor, I_p, of 1.5 if the following conditions apply:
  - 13.1.3.1 The component conveys, supports or otherwise contains toxic, highly toxic or explosive substances where the quantity of materials exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.
  - 13.2.3.4 The component conveys, supports or otherwise contains hazardous substances and is attached to a structure or portion thereof classified by the authority having jurisdiction as a hazardous occupancy.
- In addition, Section 13.2.2.2 states that special certification is required demonstrating that any component containing hazardous materials with an I_p of 1.5 will maintain containment under seismic loading. Thus any component covered by the above descriptions is a "designated seismic system" and, unless it falls under the exemption for mechanical and electrical components in Seismic Design Category B, requires engineering, special certification, special inspection, etc.

The International Fire Code (IFC) contains provisions that deal with each type of hazardous material such as corrosives, cryogenics, flammable and combustible liquids, highly toxic materials, organic peroxides, oxidizers, pyrophorics, reactive materials, and water reactive solids and liquids. Independent of any seismic concerns, there are many provisions that apply to piping systems that convey these materials. There may be requirements, such as secondary containment, backup safety systems, emergency shut-off, monitoring or leak detection. NFPA 704, Standard System for the Identification of Hazards of Materials for Emergency Response (NFPA, 2007b) provides a classification and labeling system for hazardous materials as shown in Figure 6.4.5.1-4. The four-part diamond symbol is coded by color and position for type of hazard; the hazards associated with health, flammability and reactivity are further coded by degree of hazard. Use of appropriate hazard labeling for hazardous piping and associated containers or tanks of hazardous materials, as well as buildings housing such materials, is important so that fire fighters, emergency responders, and engineers performing postearthquake inspections will be aware of the hazards present.

- Requirements for seismic shut-off valves, excess flow switches, and excess flow valves for natural gas lines may vary by jurisdiction. While some jurisdictions now require seismic shut-off valves on some types or sizes of gas lines, many utilities do not encourage their use for residential service due to the difficulty in resetting them all following an earthquake. Some jurisdictions have tried to avoid this by requiring excess flow valves instead; check the applicable jurisdiction for specific requirements in your area.
- Seismic restraint details for pressure piping shown in Sections 6.4.3.1 through 6.4.3.8 can be adapted for use with hazardous fluid piping. Nevertheless, additional care is required in the design, installation, inspection, and maintenance of hazardous fluid piping systems. They may require specialized piping analysis, more frequent supports, ductile materials, continuous piping without joints, special welding procedures, special inspections, special purpose pipe clamps to avoid scratching the pipe or to prevent corrosion, special insulation and consideration of large thermal differentials. Hazardous piping systems often require secondary containment such as double-walled piping. In addition, they may require monitoring, leak detection systems, excess flow switches, excess flow valves or seismic shut-off valves, use of protective sleeved connections, or cushion clamps. There are thousands of possible hazardous chemical streams and dozens of different pipe materials. Design of seismic restraints for these systems is a highly specialized field and may require coordination between the mechanical engineer, hazardous piping expert, and a seismic piping expert. There are currently few references available that deal specifically with the seismic issues related to these hazardous systems.

Mitigation Examples

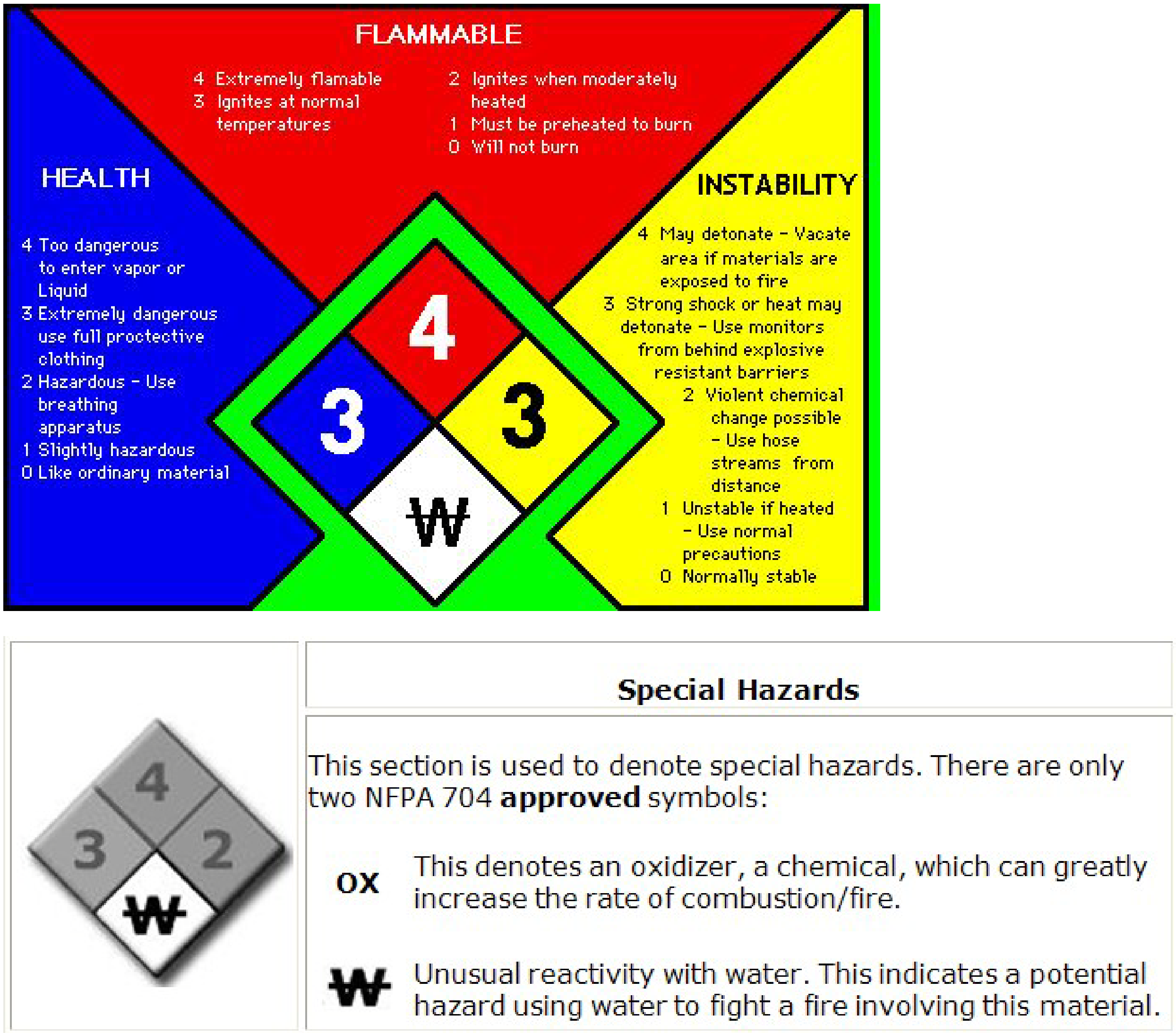


Figure 6.4.5.1-4 Example of NFPA 704 Fire Diamond used to label hazardous substances. The four divisions in the diamond are typically color-coded, with blue indicating level of health hazard, red indicating flammability, yellow (chemical) reactivity, and white containing special codes for unique hazards. Each of health, flammability and reactivity is rated on a scale from 0 (no hazard; normal substance) to 4 (severe risk). This labeling scheme is used in the U.S. but Canada, the European Union, Japan, etc. have different labeling schemes that should be followed for facilities outside the U.S.

Figure 6.4.5.1-5 Two examples of double walled piping used for secondary containment of hazardous fluids. Preassembled double walled pipe with centering devices or spacers separating the inner and outer pipe is available commercially, but as shown here, the outer pipe was installed and leak tested prior to pulling the inner pipe through. Note the yellow color coded labels indicate reactive materials; flow direction also marked prominently (Photos courtesy of Jeffrey Soulages, Intel Corporation).

Figure 6.4.5.1-6 Clockwise from top: a) Sleeved pipe connections where seismic anchorage consists of cushioned pipe clamp attached around outer sleeve and inner pipe not restrained longitudinally. b) Airgas canisters chained and strapped to supports, fitted with flexible hose, stainless steel piping (note blue label), and a row of valves. c) Label on tank shows example of European ADR danger labeling scheme. d) Excess flow valve for large gas tank (Photos courtesy of Jeffrey Soulages, Intel Corporation).

Figure 6.4.5.1-7 Process nitrogen piping outside engineering building on the UC Berkeley campus; strut clamp has rubber fittings to protect the stainless steel piping (Photos courtesy of Cynthia Perry, BFP Engineers).

Figure 6.4.5.1-8 Two examples of seismic shut-off valves in San Francisco Bay Area. Top photo at Marine Mammal Center; lower photo at six unit apartment building in Oakland (Photos courtesy of Cynthia Perry, BFP Engineers).

Mitigation Details

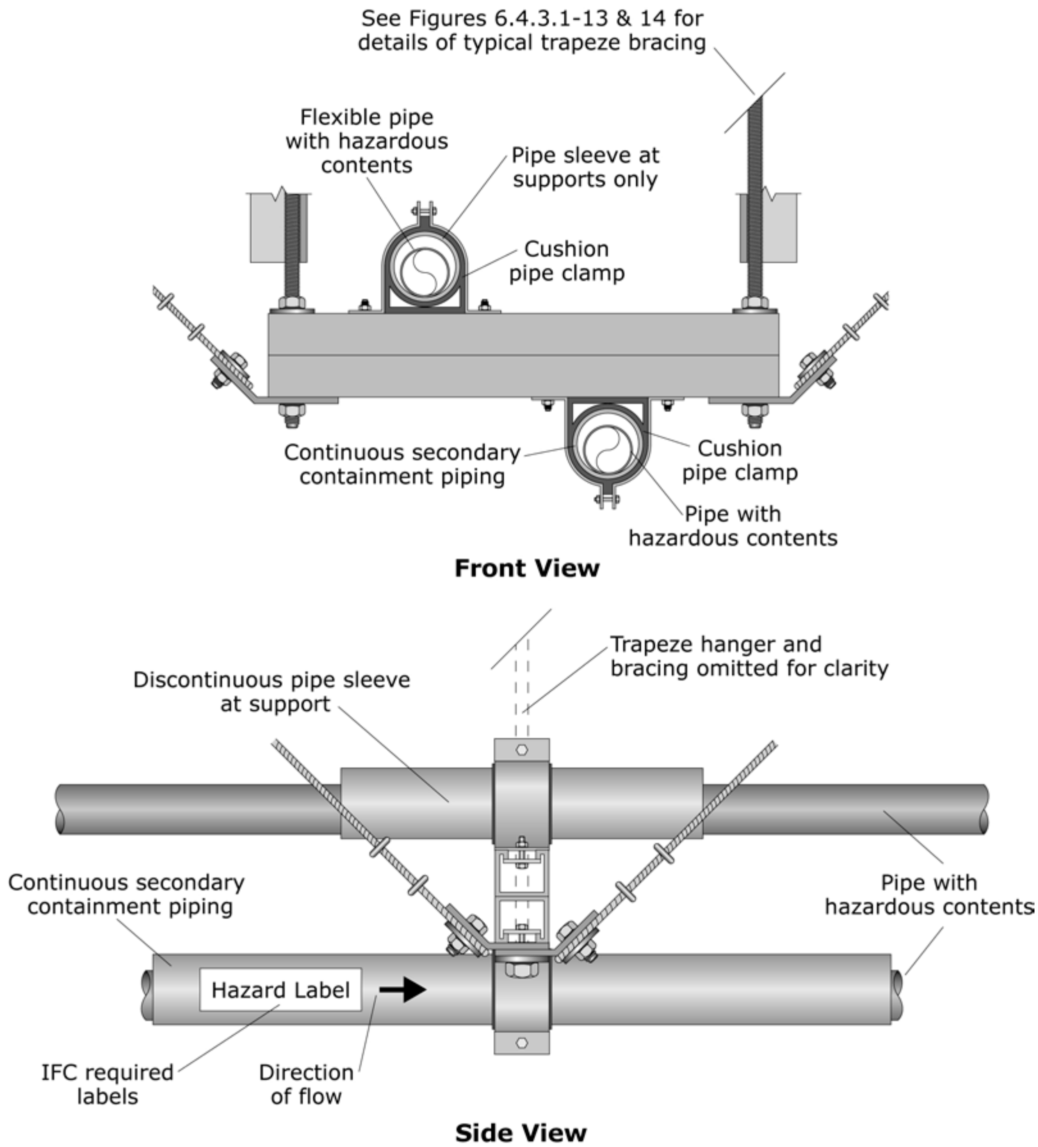


Figure 6.4.5.1-9 Hazardous piping examples (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.5 FLUID PIPING, NOT FIRE PROTECTION

6.4.5.2 NONHAZARDOUS MATERIALS PIPING

This category covers fluid piping, other than pressure piping or fire protection piping, that transfers fluids under pressure, by gravity, or that are open to the atmosphere. Pressure piping covers piping where the internal pressure is in excess of 15 psf; this category covers piping with pressures lower than 15 psf. The fluids in this category include drainage and ventilation piping, hot, cold, and chilled water piping; and piping carrying other nonhazardous liquids. These fluids, in case of line rupture, would cause property damage, but pose no immediate life safety danger. Like any other piping, failure of the pipes or pipe supports could results in falling hazards.

TYPICAL CAUSES OF DAMAGE

- Nonhazardous fluid piping is sensitive to both acceleration and deformation. Vulnerable locations include joints, bends, connections to rigidly mounted equipment and risers subjected to significant relative movement between floors. These piping systems have failure modes common to all piping systems.
- Fluids may leak from damaged joints or broken pipe; water leakage has been a major source of damage in past earthquakes.
- Damage to any part of the piping system may compromise its functionality and connected equipment or systems may be disabled due to piping leaks or failures.

Damage Examples

Figure 6.4.5.2-1 Broken copper hot water piping for at the San Carlos Hospital in the 2010 Chile Earthquake. Piping failure caused by movement of inadequately braced boiler shown at left (Photos courtesy of Gilberto Mosqueda, SUNY Buffalo).

Figure 6.4.5.2-2 Broken copper piping for hot water supply in residential building in the 2010 Chile Earthquake. Trapeze shown not laterally braced but hangers appear to be less than 12" in length and may not have required lateral restraints per ASCE 7-10 (Photo courtesy of Gokhan Pekcan).

Figure 6.4.5.2-3 Photos displaying resilience of piping systems; this building suffered a partial structural collapse along one side in the 2010 Chile Earthquake. The only broken pipe (shown at lower right) was along the collapsed side; the other piping had broken pipe supports in some locations but the joints remained largely intact, even with these very large deformations (Photos courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Seismic restraint details for pressure piping shown in Sections 6.4.3.1 through 6.4.3.8 can be adapted for use with fluid piping. The same types of suspended, wall-, floor-, or roof-mounted details also apply to these types of piping.
- Insulation must be coordinated with pipe supports; the presence of insulation or a protective sleeve between the pipe and the pipe strap or clamp may allow the pipe to slip longitudinally.
- Note that where a pipe carries water in a facility that uses magnesium, it should be treated the same as hazardous material piping due to the potentially violent reaction between some forms of magnesium and water.

Mitigation Examples

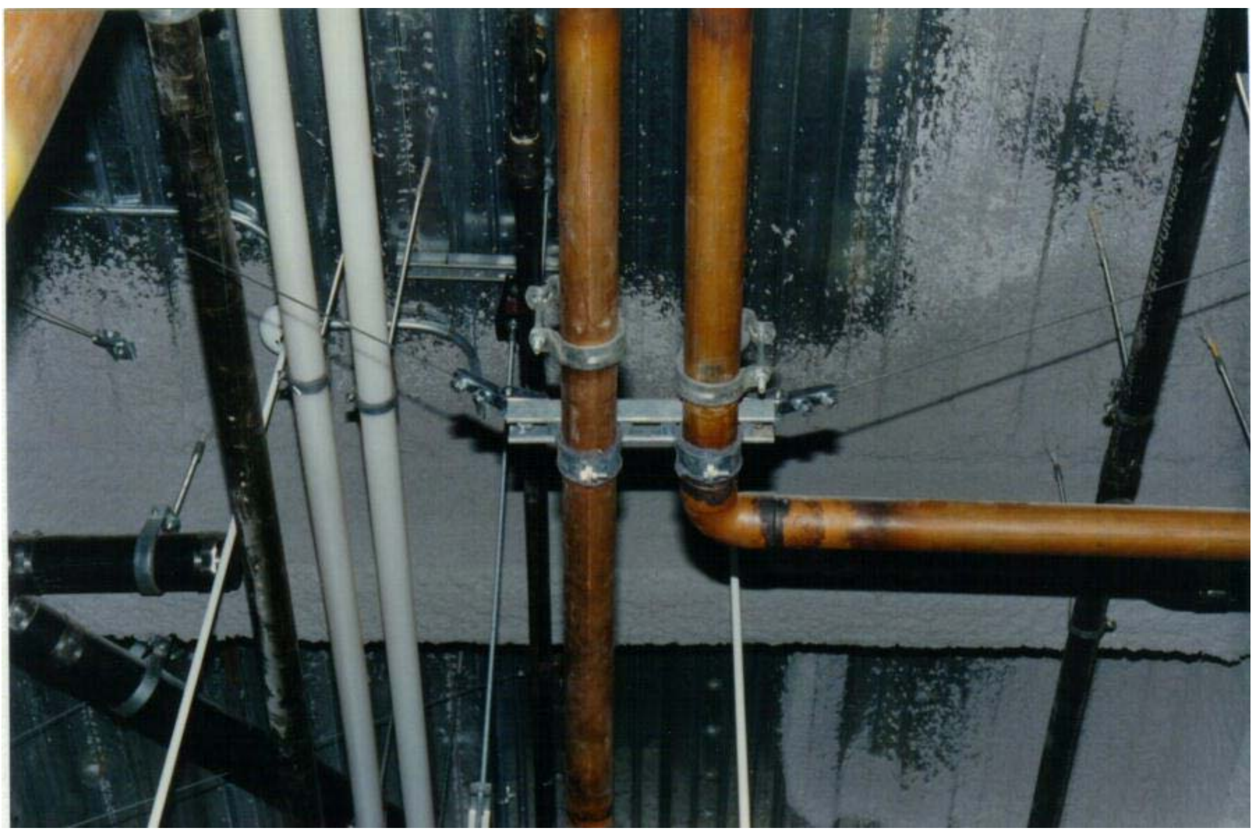


Figure 6.4.5.2-4 Cable bracing used to restrain overhead copper piping (Photo courtesy of Mason Industries).

Figure 6.4.5.2-5 Poor example of sanitary sewer pipe support installed in San Francisco Bay Area in 2010; strut clamp has inadequate edge distance to end of strut and could slip off the end (Photo courtesy of Cynthia Perry, BFP Engineers).

Figure 6.4.5.2-6 Piping installation in garage of mixed commercial/residential building San Francisco Bay Area completed in 2010. Note piping and trapeze supports do not have lateral restraints as all hangers were kept under 12" in length; only the sprinkler lines were laterally restrained. (Photo courtesy of Cynthia Perry, BFP Engineers).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.6 DUCTWORK

6.4.6.1 SUSPENDED DUCTWORK

This category covers suspended HVAC ducts; see Section 6.4.1.5 for suspended HVAC equipment.

TYPICAL CAUSES OF DAMAGE

- Unbraced ducts may swing and impact other items. They may become damaged at restraints or "hard spots" along the duct path such as at connections of braced in-line equipment, at connections to floor-mounted equipment, or at wall or slab penetrations. Inadequately supported ducts may come loose from the HVAC equipment or diffusers to which they are connected and fall.
- Ducts may be damaged by differential movement such as at building separations.

Damage Examples

Figure 6.4.6.1-1 Unbraced ducts separated at bend in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

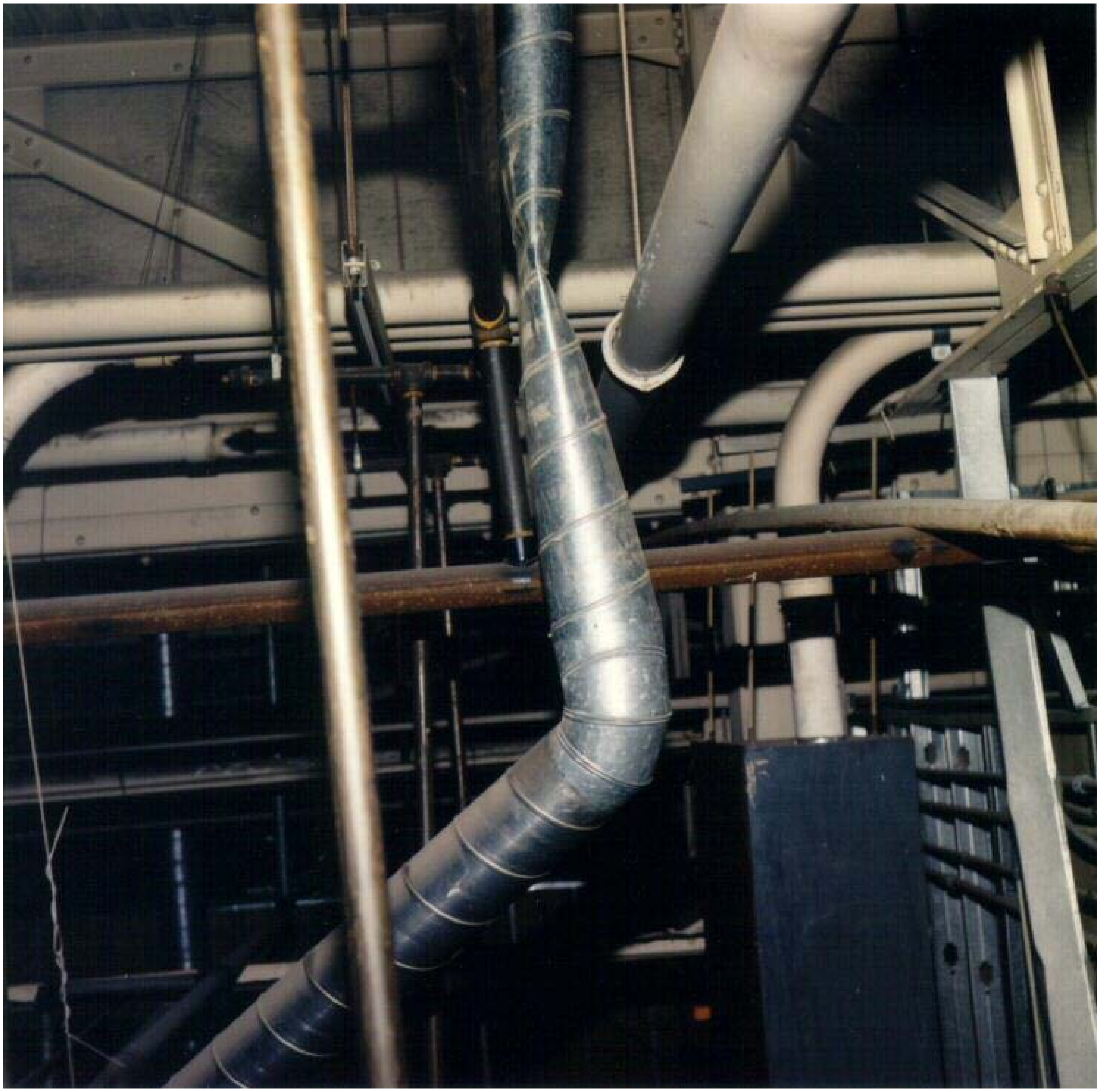


Figure 6.4.6.1-2 Unbraced duct damaged by impact with piping in 1994 Northridge Earthquake (Photo courtesy of Mason Industries).

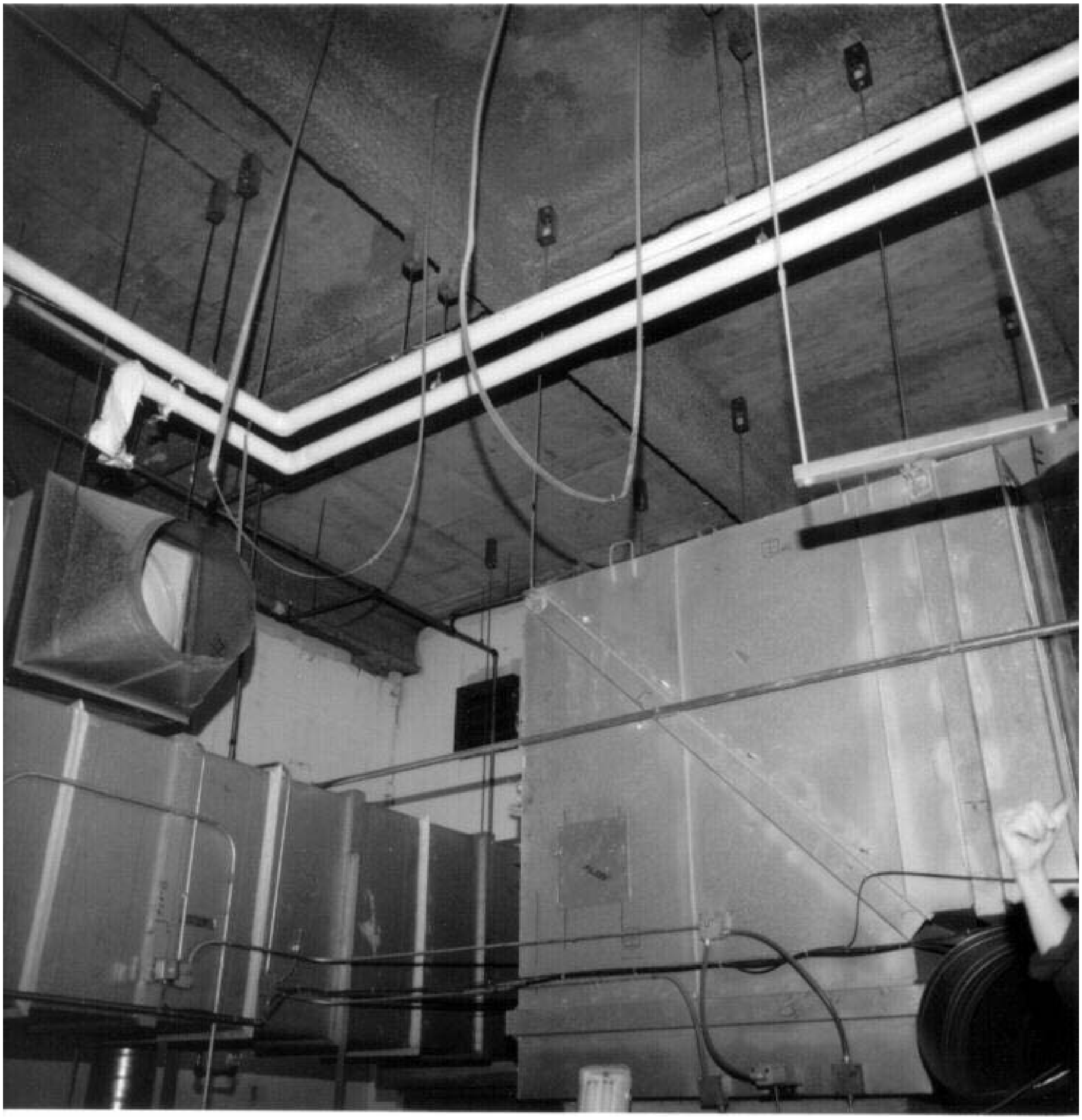


Figure 6.4.6.1-3 Collapsed unbraced ducts and hangers dangling from floor above in the 1994 Northridge Earthquake (Photo courtesy of Mason Industries).

SEISMIC MITIGATION CONSIDERATIONS

- Details shown here are for suspended ducts. Ducts may also be floor-, wall- or roof-mounted, may cross building separations, or may be located in vertical chases. Refer to FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for attachment details, for other conditions and general information about installation.

- 2006 IBC *International Building Code* (ICC, 2006) and ASCE/SEI 7-10 *Minimum Loads for Buildings and Other Structures* (ASCE, 2010) include several exemptions for suspended ducts: seismic restraints are not required under certain circumstances such as if the vertical hangers are less than 12 inches long or if the ducts have a cross-sectional area less than 6 square feet, as long as flexible duct connections are provided at connections to braced equipment. Refer to ASCE/SEI 7-10 Section 13.6.7 for more information.
- Ductwork required for HVAC systems in hospitals or other essential facilities may be classified as designated seismic systems with a component importance factor of 1.5. Such designated seismic systems may require engineering calculations, equipment certification, and additional inspections. Check ASCE 7-10 and the jurisdiction for specific requirements.

Mitigation Examples

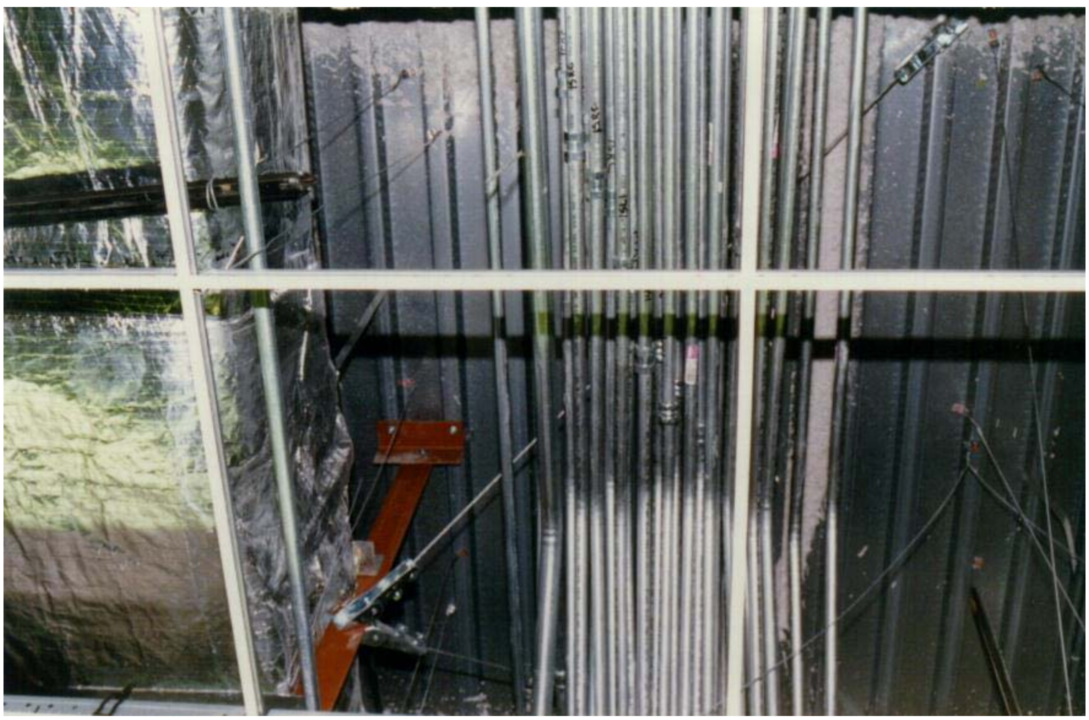
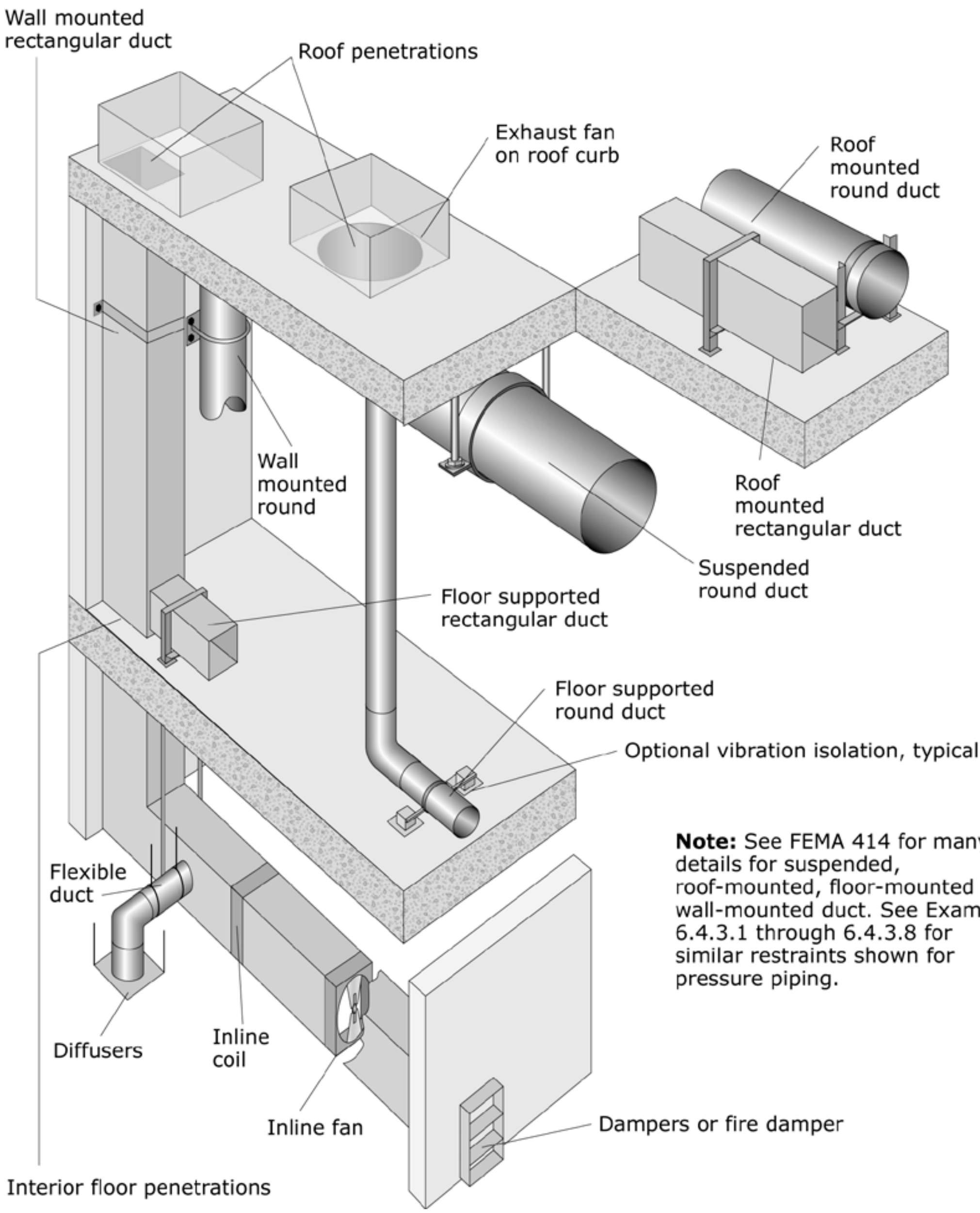


Figure 6.4.6.1-4 Rectangular duct supported by steel shapes with cable braces (Photo courtesy of Mason Industries).

Figure 6.4.6.1-5 Floor-mounted rectangular duct supported on braced support stand built up from steel angles (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.4.6.1-6 Roof-mounted rectangular duct supported on braced support stand built up from steel channels (Photo courtesy of Maryann Phipps, Estructure).

Mitigation Details



Note: See FEMA 414 for many details for suspended, roof-mounted, floor-mounted or wall-mounted duct. See Examples 6.4.3.1 through 6.4.3.8 for similar restraints shown for pressure piping.

Figure 6.4.6.1-7 Overview of ductwork restraints (ER).

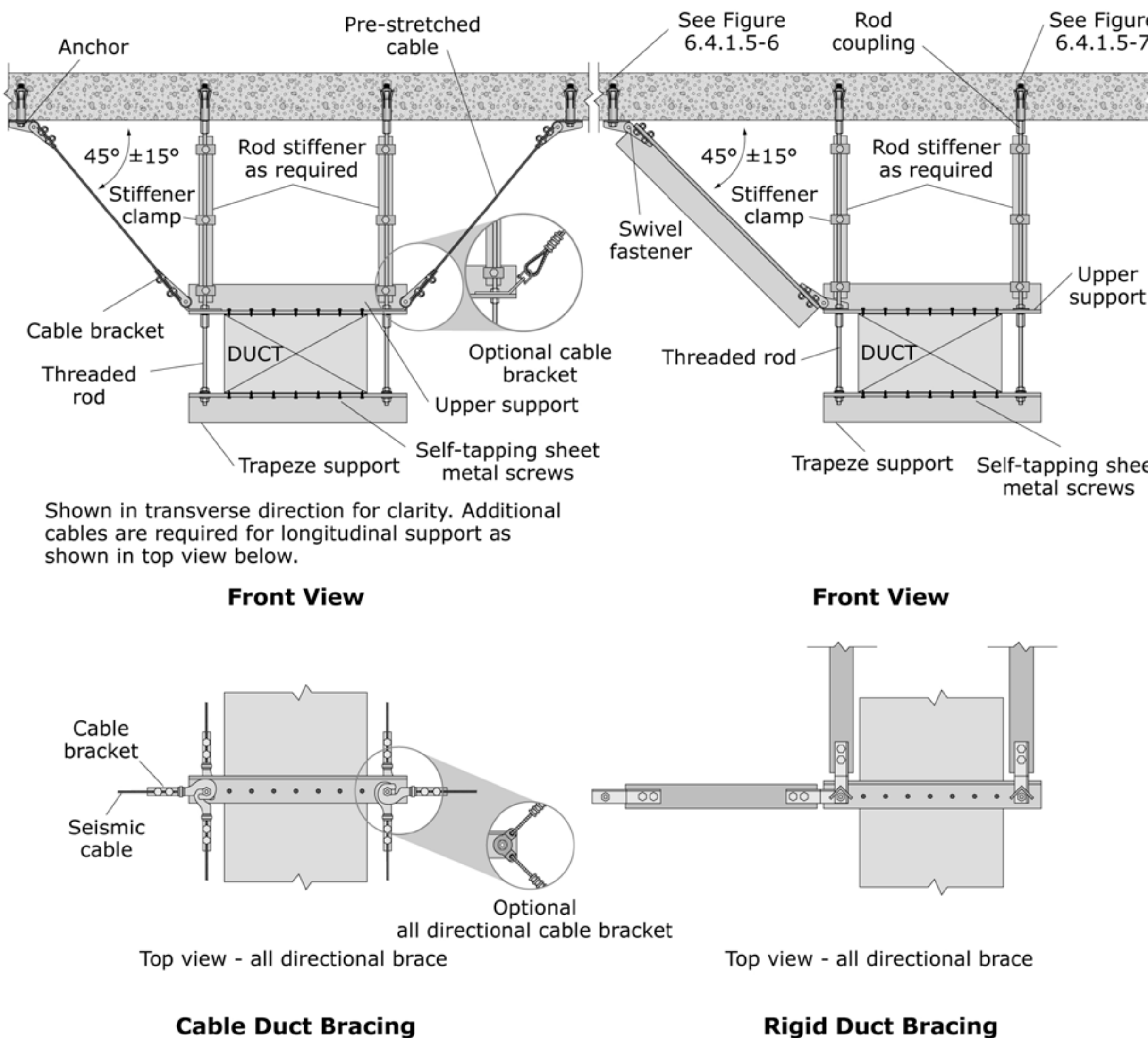


Figure 6.4.6.1-8 Suspended ductwork (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.6 DUCTWORK

6.4.6.2 AIR DIFFUSERS

This category covers suspended air diffusers or mechanical registers, typically part of a suspended ceiling system.

TYPICAL CAUSES OF DAMAGE

- Air diffusers may be a falling hazard if they are not supported independent of the ceiling. The diffuser may separate from the attached duct and fail to operate as intended.

Damage Examples

Figure 6.4.6.2-1 Air diffusers fell to the floor; ducts hanging through ceiling grid as a result of the 1994 Northridge Earthquake (FEMA 74, 1994).

Figure 6.4.6.2-2 HVAC diffuser attached to the structure with four vertical hangers; ceiling system was damaged beyond repair in the 2001 Peru Earthquake but none of the diffusers or lights fell. Ceiling was demolished prior to photo (Photo courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Requirements for ceiling mounted services in suspended acoustic ceilings are covered in ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010). Air diffusers and other ceiling-mounted services weighing less than 20 lb must have positive attachment to the ceiling grid. In addition to positive attachment to the grid, services weighing between 20 lb and 56 lb must have two 12 gauge safety wires connected to the structure above or to the ceiling hanger wires to prevent them from falling. Two diagonally opposite vertical safety wires can keep them from posing a risk to occupants below. Services weighing above 56 lb must be supported directly from the structure above by approved hangers; in some cases this can be accomplished with 4 taut 12 gauge wires, one located at each corner of the service. While ASTM E580 does not require safety wires for items weighing less than 20 lb, use of at least one wire may be good practice considering the number of diffusers that have come down in recent earthquakes.

- Only intermediate duty or heavy duty grid may be used to support suspended acoustic ceilings with lights and mechanical services attached. For Seismic Design Category D, E & F, only heavy duty grid may be used. See Section 6.3.4.1 for additional ceiling requirements. For an existing unbraced ceiling, the addition of four diagonal wire braces at each corner of diffusers will limit horizontal movement of the diffuser and prevent impact with other suspended items. Diffuser restraints should be coordinated with the lateral restraints for the ceiling grid and may require engineering expertise.
- Do not brace diffusers to ducts, piping, or other nonstructural items.

Mitigation Details

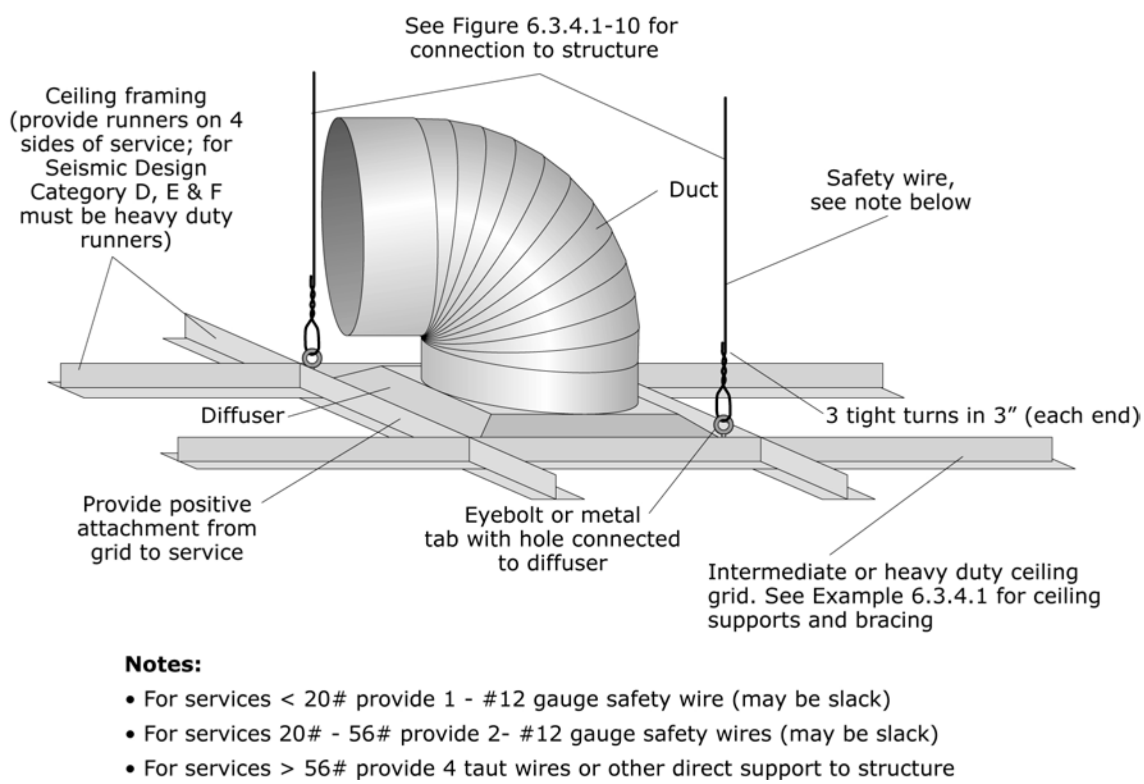


Figure 6.4.6.2-3 Ceiling-mounted diffuser (NE, ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.7 ELECTRICAL AND COMMUNICATIONS EQUIPMENT

6.4.7.1 CONTROL PANELS, MOTOR CONTROL CENTERS, AND SWITCHGEAR

This category includes tall, narrow floor-mounted electrical items in sheet metal cabinets such as electrical control panels, motor control centers, switchgear, and substations.

TYPICAL CAUSES OF DAMAGE

- Overturning or sliding due to lack of anchorage or inadequate anchorage.
- Loss of function due to failure of internal components caused by inertial forces.
- Damaged electrical equipment may cause electrical hazards and fire hazards.

Damage Example

Figure 6.4.7.1-1 Overturned equipment in the 1985 magnitude-8 Mexico Earthquake (Photo courtesy of Degenkolb Engineers).

Figure 6.4.7.1-2 Unanchored electrical cabinets overturned in a paper products plant during the 1999 magnitude-7.4 Izmit, Turkey earthquake (Photo courtesy of NISEE Izmit Collection, No. IZT-682, photograph by Halil Sezen).

Figure 6.4.7.1-3 Damage to unanchored electrical cabinets at power plant in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Working around electrical equipment can be extremely hazardous. Read the Electrical Danger Warning and Guidelines in Section 6.6.8 of this document before proceeding with any work.
- Many of these components can be supplied with shop welded brackets or predrilled holes for base or wall anchorage. For any new equipment, request items that can be supplied with seismic anchorage details.
- See Section 6.4.1.1 for additional base anchorage details. Refer to FEMA 413 *Installing Seismic Restraints for Electrical Equipment* (2004) for general information on seismic anchorage of electrical equipment.

Mitigation Examples

Figure 6.4.7.1-4 Equipment cabinets retrofitted with unidirectional snubbers at base (Photo courtesy of Mike Griffin).

Figure 6.4.7.1-5 Installation that performed well in the 2010 magnitude-8.8 Chile Earthquake; cabinets anchored at base. Some cabinets tied together side by side using existing lifting hooks at top of cabinets (Photos courtesy of Rodrigo Retamales, Ruben Boroschek & Associates).

Figure 6.4.7.1-6 Close up of snubbers (Photo courtesy of Mike Griffin).

Figure 6.4.7.1-7 Postearthquake strengthening of anchorage for electrical cabinets from the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.7.1-8 Detail of postearthquake strengthening from the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.7.1-9 Anchorage for electrical cabinets. Anchorage to wall at top of cabinets is also present but not visible (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.4.7.1-10 Detail of cabinet base anchorage (Photo courtesy of Maryann Phipps, Estructure).

Mitigation Details

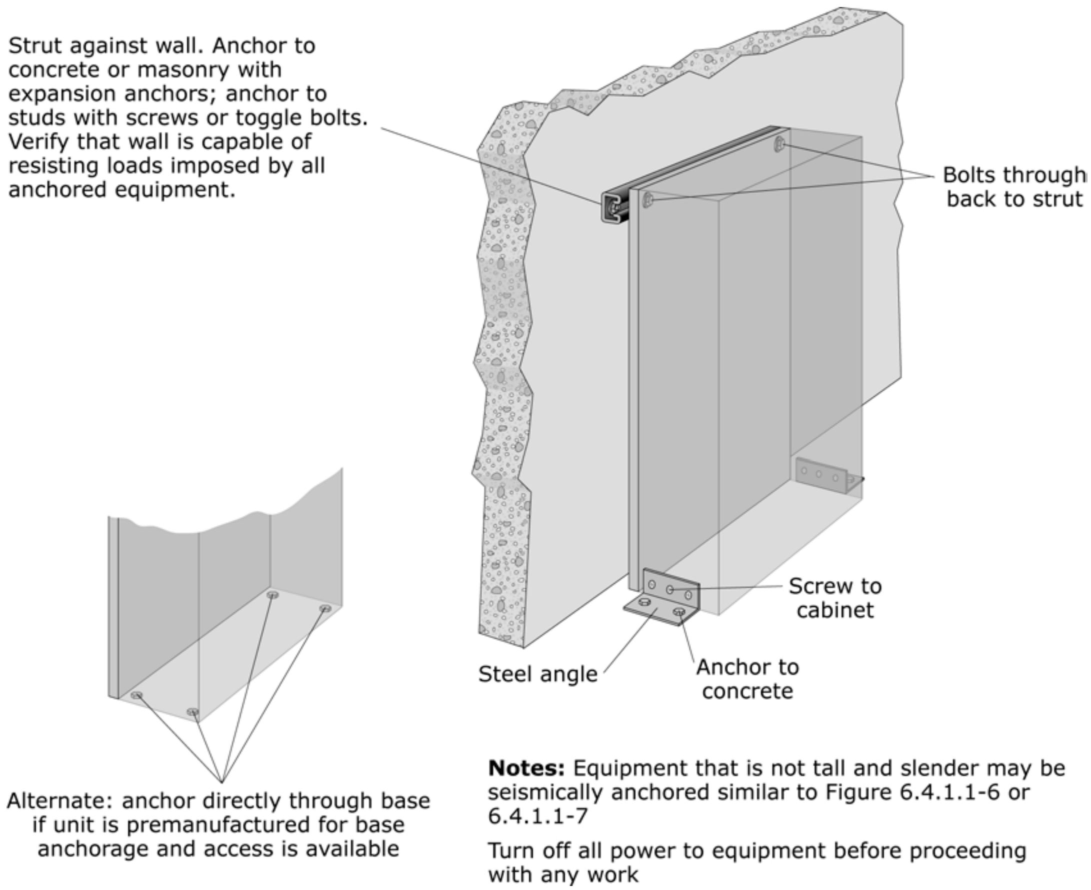


Figure 6.4.7.1-11 Electrical control panels, motor controls centers, or switchgear (ER).

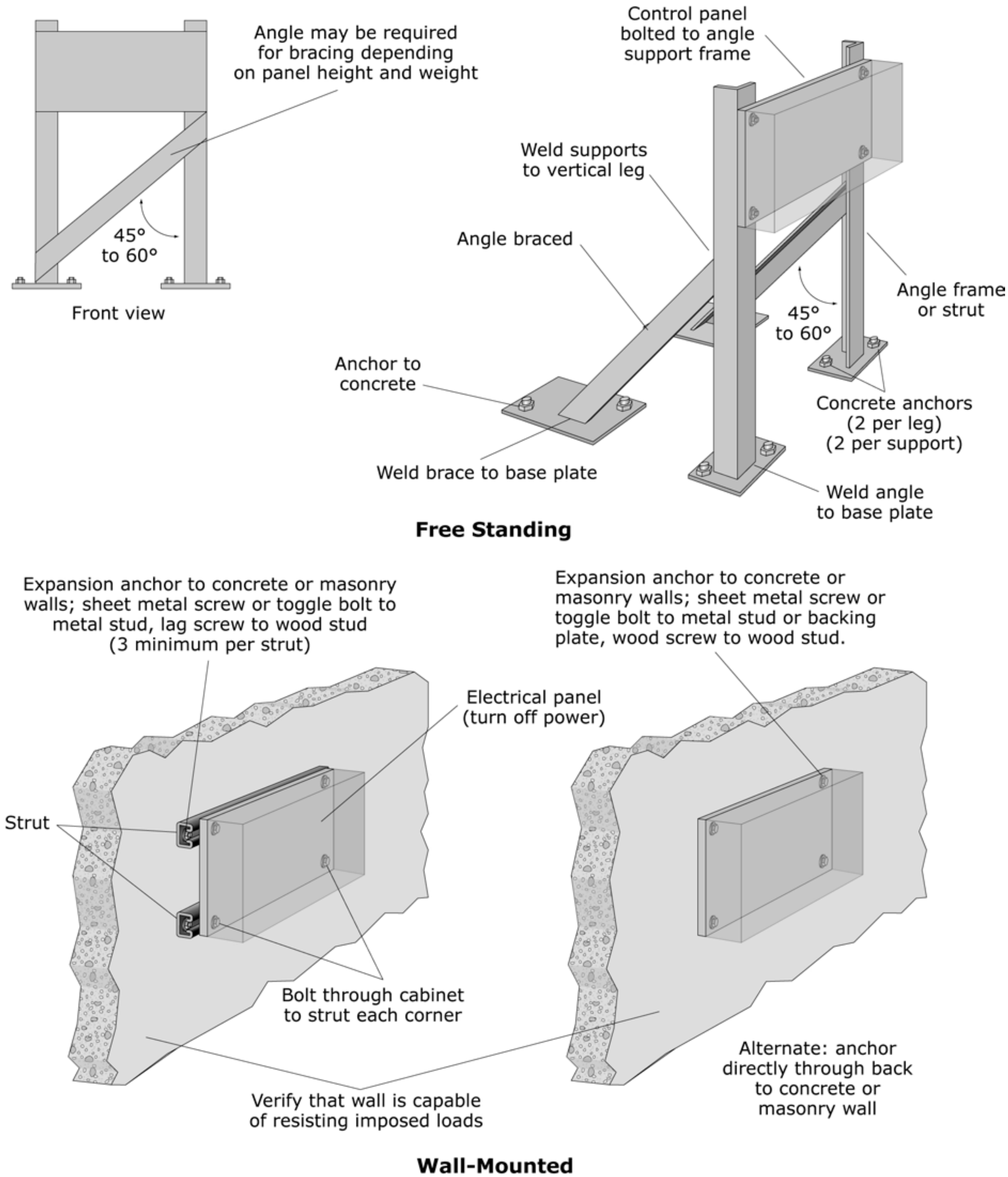


Figure 6.4.7.1-12 Free-standing and wall-mounted electrical control panels, motor controls centers, or switchgear (ER).